Chapter 7: Bioaccumulation of Contaminants in Fish Tissues

INTRODUCTION

Bottom dwelling (i.e., demersal) fishes are collected as part of the Point Loma Ocean Outfall (PLOO) monitoring program to assess the accumulation of contaminants in their tissues. Bioaccumulation in fish occurs through biological uptake and retention of chemical contaminants derived from various exposure pathways (Tetra Tech 1985). Exposure routes for demersal fishes include the adsorption or absorption of dissolved chemical constituents from the water and the ingestion and assimilation of pollutants from food sources. Fish may also accumulate pollutants by ingesting pollutant-containing suspended particulate matter or sediment particles. Demersal fishes are useful in biomonitoring programs because of their proximity to bottom sediments. For this reason, levels of contaminants in tissues of these fishes are often related to those found in the environment (Schiff and Allen 1997).

The bioaccumulation portion of the PLOO monitoring program consists of 2 components: (1) liver tissues analyzed from trawl-caught fishes; (2) muscle tissues analyzed from fishes collected by rig fishing. Fishes collected from trawls are considered representative of the demersal fish community, and certain species are targeted based on their ecological significance (i.e., prevalence in the community). Chemical analyses are performed using livers because this is the organ where contaminants typically concentrate. In contrast, fishes targeted for collection by rig fishing represent species from a typical sport fisher's catch, and are therefore of recreational and commercial importance. Muscle tissue is analyzed from these fish because it is the tissue most often consumed by humans, and therefore the results have human health implications.

All muscle and liver samples were analyzed for contaminants as specified in the NPDES discharge permit governing the PLOO monitoring program. Most of these contaminants are also sampled for the NOAA National Status and Trends Program. NOAA initiated this program to detect changes in the quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of concern for the environment (Lauenstein and Cantillo 1993). This chapter presents the results of all tissue analyses that were performed during 2005.

MATERIALS AND METHODS

Collection

Pacific sanddabs (*Citharichthys sordidus*) were collected by trawl in 4 zones and various rockfish (*Sebastes* spp) were collected at 2 rig fishing stations (RF1 and RF2) during October 2005 (**Figure 7.1, Table 7.1**). Zone 1 includes the two nearfield trawl stations, SD10 and SD12, located just south and just north of the PLOO, respectively; Zone 2 includes the two northern farfield trawl

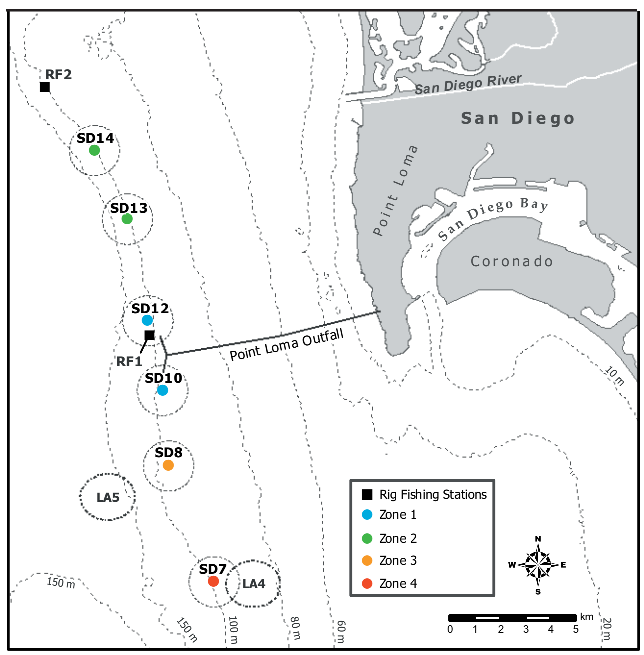

Figure 7.1
Otter trawl and rig fishing stations/zones surrounding the City of San Diego's Point Loma Ocean Outfall.

Table 7.1
Species of fish collected for tissue analysis from each trawl zone or rig fishing station (RF1–RF2) as part of the PLOO monitoring program during October 2005.

Station	Rep 1	Rep 2	Rep 3
Zone 1	Pacific sanddab	Pacific sanddab	Pacific sanddab
Zone 2	Pacific sanddab	Pacific sanddab	Pacific sanddab
Zone 3	Pacific sanddab	Pacific sanddab	Pacific sanddab
Zone 4	Pacific sanddab	Pacific sanddab	Pacific sanddab
RF1	Rosethorn rockfish	Mixed rockfish	Mixed rockfish
RF2	Squarespot rockfish	Squarespot rockfish	Speckled rockfish

stations, SD13 and SD14; Zone 3 is trawl station SD8, located near the LA-5 dredged materials dumpsite; Zone 4 is trawl station SD7, located several kilometers to the south of the outfall. Sanddabs were collected, measured and weighed following guidelines described in Chapter 6 of this report. Rockfish were collected at rig fishing sites using primarily rod and reel fishing tackle following standard procedures (City of San Diego in prep). Only fishes >13 cm standard length were retained for tissue analyses. These fishes were sorted into composite samples, each containing a minimum of 3 individuals. The fishes were then wrapped in aluminum foil, labeled, put in ziplock bags, and placed on dry ice for transport to the freezer in the Marine Biology Laboratory.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis (see City of San Diego in prep). Each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus prior to dissection. The standard length (cm) and weight (g) of each fish were recorded (**Appendix D.1**). Dissections were carried out on Teflon pads that were cleaned between samples. Tissue samples were then placed in glass jars, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City of San Diego Wastewater Chemistry Laboratory within 10 days of dissection.

Tissue samples were analyzed for the chemical constituents specified by the permit under which this sampling was performed. These chemical constituents include trace metals, chlorinated pesticides, PCBs, and PAHs as listed in **Appendix D.2**. Values for all parameters detected in each sample are summarized in **Appendix D.3**. Estimated values are included for some parameters determined to be present in a sample with high confidence (i.e., peaks are confirmed by mass-spectrometry), but at levels below the MDL. A detailed description of the analytical protocols may be obtained from the City of San Diego Wastewater Chemistry Laboratory (City of San Diego 2006).

RESULTS

Contaminants in Trawled Fish

Metals

Twelve metals, including aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, selenium, thallium, and zinc occurred in over 80% of the liver samples analyzed from Pacific sanddabs collected by trawl in 2005 (**Table 7.2**). Antimony, mercury, nickel, and tin were also detected, but less frequently. Although silver and tin were detected in almost all of the Pacific sanddab samples collected in 2004, tin was detected in less than 10% of the samples this year and silver was not detected at all. Concentrations of most metals were < 7 ppm. Exceptions occurred for iron and zinc, which had concentrations above 20 ppm in at least one sample.

Table 7.2

Concentrations of metals, total PCB, and pesticides detected in liver tissues from trawl-caught Pacific sanddabs during October 2005. n=number of detected values out of 12 samples.

Parameter	n	Min	Max	Mean
Metals (ppm)				
Aluminum	11	1.12	11.70	6.98
Antimony	6	0.57	1.25	0.91
Arsenic	12	4.27	6.07	5.39
Barium	12	0.01	0.25	0.10
Cadmium	12	1.37	8.75	4.41
Chromium	10	0.21	3.10	0.70
Copper	12	2.33	7.37	4.16
Iron	12	33.30	124.00	63.44
Lead	12	0.47	1.42	0.86
Manganese	12	0.56	1.18	0.84
Mercury	8	0.03	0.09	0.05
Nickel	8	0.10	1.25	0.32
Selenium	12	0.44	0.88	0.62
Thallium	12	4.60	6.35	5.76
Tin	1	0.25	0.25	0.25
Zinc	12	15.70	22.10	19.16
Pesticides (ppb)				
Total DDT	12	147.30	534.50	322.73
Lindane				
BHC (beta isomer)	1	5.70	5.70	5.70
BHC (delta isomer)	1	3.40	3.40	3.40
HCB, Hexachlorobenzene	12	2.40	4.70	3.32
Chlordane				
alpha (*cis*) Chlordane	12	4.10	8.70	5.63
gamma (*trans*) Chlordane	1	1.90	1.90	1.90
cis-Nonachlor	10	2.50	4.80	3.21
trans-Nonachlor	12	4.50	11.00	6.45
Total PCB (ppb)	12	76.70	321.20	189.76
Lipids (%wt)	12	43.5	60.90	48.55

Comparisons of the frequently detected metals from samples collected closest to the discharge (Zone 1) to those located farther away (Zones 2–4) suggest that there was no clear relationship between contaminant loads and proximity to the outfall (**Figure 7.2**). Instead, other patterns were suggested by the data. For example, the highest mean values of chromium, lead, manganese, mercury, nickel, and zinc occurred in Zone 3, the zone closest to the LA-5 dredge material site. However, the data were too variable to determine if these trends were significant.

Pesticides and PCBs

Several chlorinated pesticides were detected in liver tissues during 2005 (**Table 7.2**). Total DDT (tDDT; see Appendix D.2 for individual components) was found in all samples at concentrations ranging from about 147 to 535 ppb.

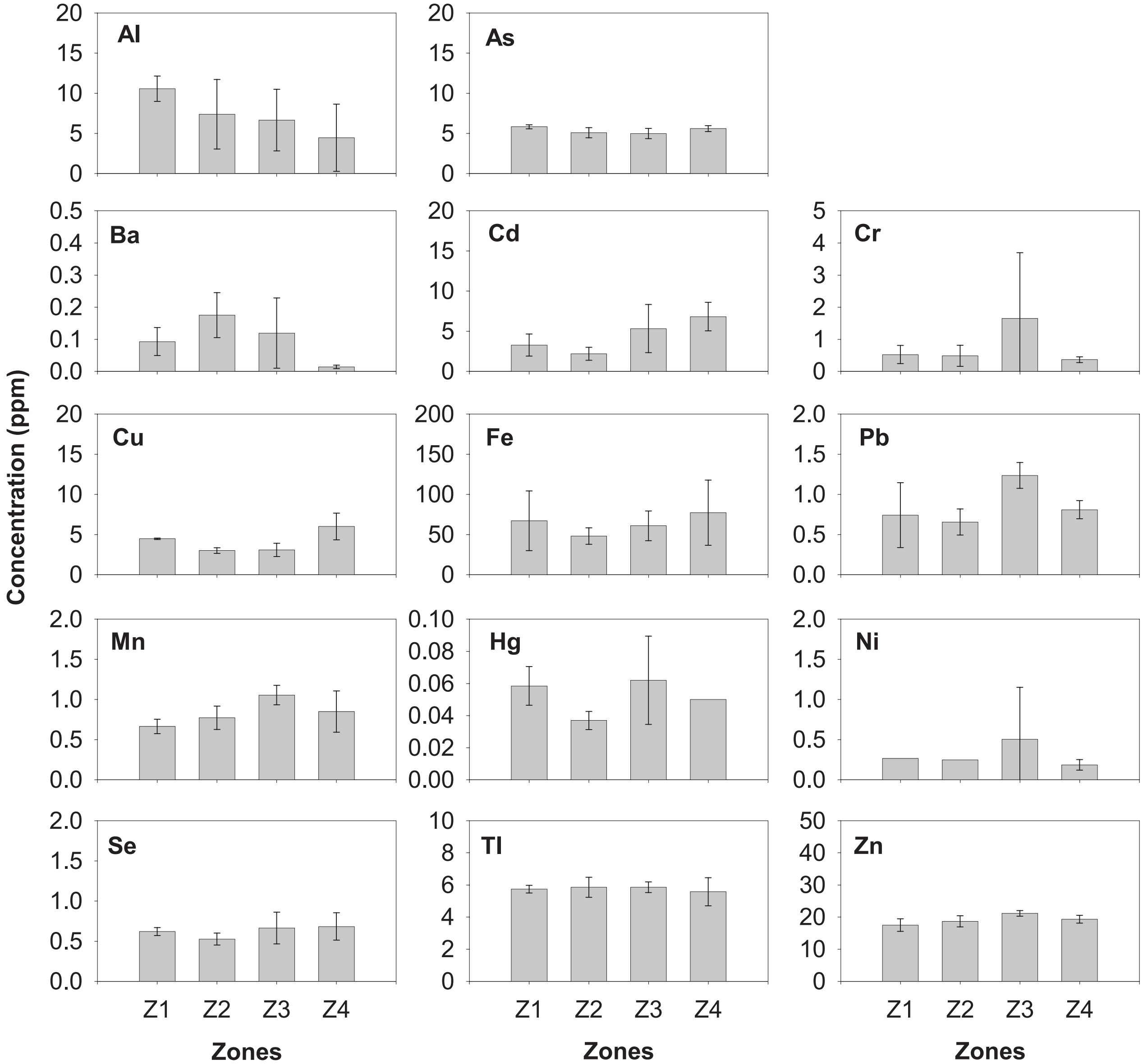

Figure 7.2

Concentrations of metals detected frequently in liver tissues of trawl-caught Pacific sanddabs collected during October 2005 at Zones 1–4 (Z1–Z4) off Point Loma. Data are means ± 1 STD; n is between 1 and 3, depending on the number of samples with detected values. Zone 1 represents the zone located closest to the discharge site.

Other pesticides that were detected frequently included hexachlorobenzene (HCB), alpha (*cis*) Chlordane, *cis*-Nonachlor, and *trans*-Nonachlor. In contrast, BHC (Lindane) and gamma (*trans*) Chlordane were rarely detected. The maximum concentration for any one of these pesticides was 11 ppb (*trans*-Nonachlor), which was very low relative to total DDT.

PCBs occurred in all samples. Concentrations for the individual PCB congeners are listed separately in Appendix D.3. Total PCB concentrations (i.e., the sum of all congeners detected in a sample, tPCB) were variable, ranging from about 77 to 321 ppb, with a mean of approximately 190 ppb.

As with metals, there was no clear relationship between concentrations of the frequently occurring pesticides or PCBs and proximity to the outfall (**Figure 7.3**). Generally, higher values of tPCB, tDDT, alpha (*cis*) Chlordane, *cis*- and *trans*- Nonachlor occurred in Zones 1, 3 or 4, but these values were not substantially different from those that occurred in Zone 2.

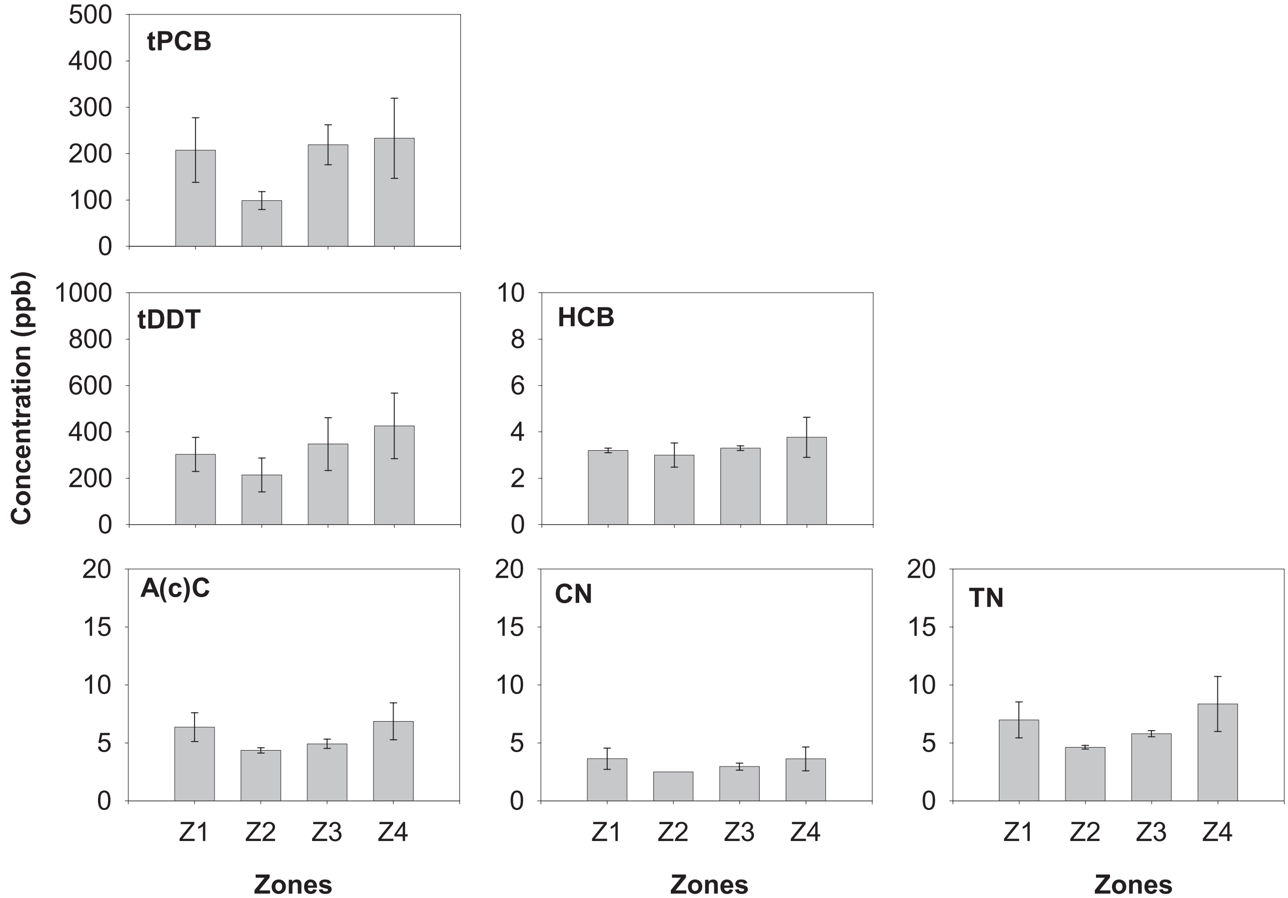

Figure 7.3
Concentrations of frequently detected chlorinated pesticides (tDDT=total DDT; HCB=hexachlorobenzene; A(c)C=alpha (*cis*) Chlordane; CN=*cis*-Nonachlor; TN=*trans*-Nonachlor) and total PCB detected in liver tissues of trawl-caught Pacific sanddabs during October 2004 at Zones 1–4 (Z1–Z4) off Point Loma. Data are means ± 1 STD; n is between 1 and 3, depending on the number of samples with detected values. Zone 1 represents the zone located closest to the discharge site.

Contaminants in Fishes Collected by Rig Fishing

Aluminum, arsenic, barium, copper, iron, manganese, mercury, selenium, thallium, and zinc occurred in at least two-thirds of the muscle tissue samples from various rockfish collected at rig fishing stations in 2005 (**Table 7.3**). Chromium, lead, and silver were also detected, but only in one-half or fewer of the samples. The metals with the highest mean concentrations included aluminum, arsenic, iron, thallium, and zinc. Each exceeded 2 ppm for at least one species of fish sampled; however there was little difference between species relative to the mean concentration for these metals. Other contaminants, such as DDT and PCB, were detected in 100% of the muscle samples, while the pesticides BHC (Lindane), HCB, and Chlordane were found much less frequently (**Table 7.4**).

To address human health concerns, concentrations of constituents found in muscle tissue samples were compared to both national and international limits and standards (Tables 7.3, Table 7.4). The United States Food and Drug Administration (FDA) has set limits on the amount of mercury, total DDT, and Chlordane in seafood that is to be sold for human consumption and there are also international standards for acceptable concentrations of various metals (see Mearns et al. 1991). While many compounds were detected in the muscle tissues of fish collected as part of the PLOO monitoring program, only arsenic and

Table 7.3

Metals detected in muscle tissues from fishes collected at PLOO rig fishing stations during October 2005. Data are compared to U.S. FDA action limits and median international standards when possible. Bold values exceed these standards; n=number of detected values; nd=not detected.

	Al	As	Ba	Cr	Cu	Fe	Pb	Mn	Hg	Se	Ag	Th	Zn
Mixed rockfish													
N (out of 2)	1	2	2	1	2	2	nd	2	2	2	nd	2	2
Min	3.28	**2.60**	0.011	0.048	0.73	1.7	—	0.05	0.05	**0.347**	—	2.6	3.1
Max	3.28	**2.87**	0.064	0.048	1.01	2.9	—	0.07	0.11	**0.478**	—	2.9	3.1
Mean	3.28	**2.74**	0.037	0.048	0.87	2.3	—	0.06	0.08	**0.412**	—	2.8	3.1
Rosethorn rockfish													
N (out of 1)	1	1	1	nd	1	1	nd	1	1	1	nd	1	1
Value	1.09	**2.49**	0.013	—	0.76	2.0	—	0.08	0.11	**0.367**	—	2.6	2.9
Speckled rockfish													
N (out of 1)	1	1	nd	nd	1	1	1	1	1	1	1	1	1
Value	1.87	**1.71**	—	—	0.27	2.2	0.34	0.05	0.07	**0.352**	0.5	2.62	3.0
Squarespot rockfish													
N (out of 2)	1	2	1	1	2	2	2	2	2	2	nd	2	2
Min	2.47	**2.16**	0.008	0.087	0.25	3.7	0.32	0.03	0.21	0.275	—	2.8	3.2
Max	2.47	**2.54**	0.008	0.087	0.46	5.0	0.42	0.06	0.26	**0.364**	—	2.9	3.4
Mean	2.47	**2.35**	0.008	0.087	0.36	4.3	0.37	0.04	0.24	**0.320**	—	2.9	3.3
ALL SPECIES													
% Detected	67	100	67	33	100	100	50	100	100	100	17	100	100
US FDA Action Limit*									1				
Median International Standard*		1.40		1.0	20		2		0.5	0.3			70

*From Mearns et al. 1991. US FDA mercury action limits and all international standards are for shellfish, but are often applied to fish. All limits apply to the sale of seafood for human consumption.

selenium had concentrations that were higher than international standards.

In addition to addressing health concerns, spatial patterns were assessed for total DDT and total PCB, as well as all metals that occurred frequently in muscle tissue samples (**Figure 7.4**). A single sample of mixed rockfish at RF1 had concentrations of tPCB, tDDT, and barium that were well above other samples. These parameters were detected in a sample that included tissue from a rockfish that was 7 cm larger than all other fishes collected (39 cm SL vs < 32 cm SL), indicating that this fish was likely much older than the other fishes and therefore had a longer exposure to the sediments. Overall, concentrations of metals, HCB, DDT, and PCB were somewhat variable in the muscle tissues from fishes at both rig fishing stations, and there was no evident relationship with proximity to the outfall.

Comparison of contaminant loads between RF1 and RF2 should be considered with caution

Table 7.4

Concentrations of chlorinated pesticides, PCBs, and lipids detected in muscle tissues from rockfish collected at rig fishing stations during October 2005. Data are compared to U.S. FDA action limits and median international standards when possible. BHC(B)=BHC, beta isomer; BHC(D)=BHC, delta isomer; HCB=hexachlorobenzene; A(c)C=alpha (*cis*) Chlordane; G(t)C= gamma (*trans*) Chlordane; CN=*cis*-Nonachlor; TN=*trans*-Nonachlor. Values are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt). n=number of detected values, nd=not detected.

	Total	Lindane			Chlordane				Total	
	DDT	BHC(B)	BHC(D)	HCB	A(c)C	G(t)C	CN	TN	PCB	Lipids
Mixed rockfish										
N (out of 2)	2	nd	nd	2	2	1	1	2	2	2
Min	11	—	—	0.1	0.3	0.3	0.5	0.4	6	2.31
Max	63.6	—	—	0.3	0.7	0.3	0.5	1.2	34.4	3.13
Mean	37.3	—	—	0.2	0.5	0.3	0.5	0.8	20.2	2.72
Rosethorn rockfish										
N (out of 1)	1	nd	nd	nd	nd	nd	nd	nd	1	1
Value	2.3	—	—	—	—	—	—	—	0.8	0.3
Speckled rockfish										
N (out of 1)	1	nd	nd	1	nd	nd	nd	nd	1	1
Value	5.7	—	—	0.1	—	—	—	—	1.3	1.4
Squarespot rockfish										
N (out of 2)	2	1	1	2	1	1	nd	1	2	2
Min	12.4	5.8	7.6	0.1	0.9	1.0	—	0.4	3.2	2.09
Max	15.1	5.8	7.6	0.2	0.9	1.0	—	0.4	3.8	2.76
Mean	13.75	5.8	7.6	0.15	0.9	1.0	—	0.4	3.5	2.425
ALL SPECIES										
% Detected	100	17	17	83	50	33	17	50	100	
US FDA Action Limit*	5000									
Median International Standard*	5000									

*From Table 2.3 in Mearns et al. 1991. USFDA action limit for total DDT is for fish muscle tissue, US FDA mercury action limits and all international standards are for shellfish, but are often applied to fish. All limits apply to the sale of seafood for human consumption.

however, because different species of fish were collected at the two sites. All specimens belong to the same family, Scorpaenidae, and have similar life histories (e.g., bottom dwelling tertiary carnivores), so they have similar mechanisms of exposure (e.g., exposure from direct contact with the sediments and through possibly similar food sources). These species are therefore comparable to a certain degree. However, since they are not the same species, differences in physiology and food choices may exist that could affect the accumulation of contaminants.

SUMMARY AND CONCLUSIONS

Twelve trace metals, 3 pesticides, and a combination of PCBs were each detected in over 80% of the liver samples from Pacific sanddabs collected around the Point Loma Ocean Outfall (PLOO) in 2005. Contaminant loads were within the range of those reported previously for other Southern California Bight (SCB) fish assemblages (see Mearns et al. 1991, Allen et al. 1998, 2002). In addition, concentrations of these contaminants

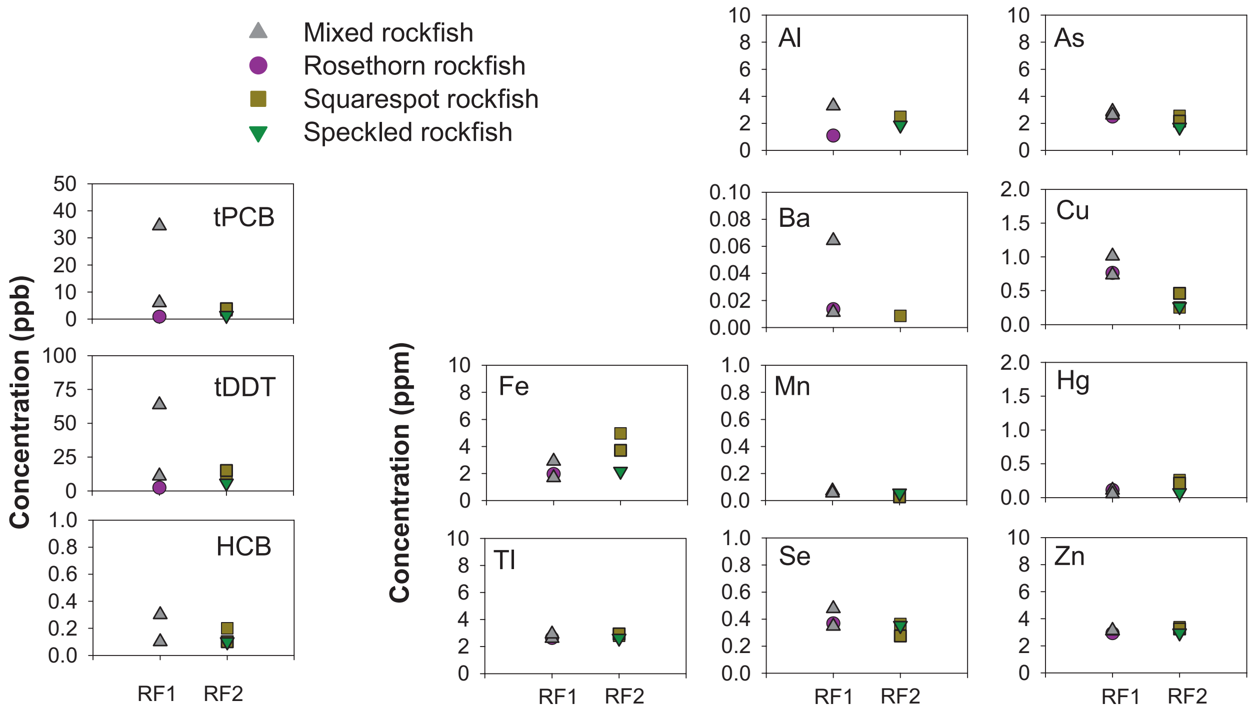

Figure 7.4
Concentrations of frequently detected metals, hexachlorobenzene (HCB), total DDT and total PCB in muscle tissues of fishes collected from each PLOO rig fishing station during 2005. Missing data represent concentrations below detection limits. RF1 represents the area located closest to the discharge site.

were generally similar to those reported previously by the City of San Diego (City of San Diego 1996–2004). Concentrations of most parameters were similar across zones/stations, and no clear relationship with proximity to the outfall was evident.

The occurrence of metals and chlorinated hydrocarbons in PLOO fish tissues may be due to many factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals (e.g., aluminum and iron) occur naturally in the environment, although little information is available on their background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history of different fish species. For example, exposure to contaminants can vary greatly between species and also among individuals of the same species depending on migration habits (Otway 1991). Fish may be exposed to contaminants in one highly contaminated area and then move into an area that is less contaminated. This may explain why many of the pesticides and PCBs detected in fish collected off Point Loma in 2005 were found in low concentrations or were not detected at all in sediments surrounding the outfall (see Chapter 4). In addition, differences in feeding habits, age, reproductive status, and gender can affect the amount of contaminants a fish will retain in its tissues (e.g., Connell 1987, Evans et al. 1993). These factors make comparisons of contaminants among species and between stations difficult.

Overall, there was no evidence that fishes collected in 2005 were contaminated by the discharge of waste water from the PLOO. Concentrations of mercury and DDT in muscle tissues from sport fish collected in the area were below FDA human consumption limits. Finally, there was no other indication of poor fish health in the region, such as the presence of fin rot or other physical anomalies (see Chapter 6).

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